during 1828, engaged on some hydrographical work off this coast, and good-naturedly assisted the littoral zone workers, enabling them to use the dredge in somewhat deeper water than they could reach from a row-boat. The results of these investigations were laid before the Academy of Sciences in July and November, 1829, and formed the subject of an elaborate report presented to the Academy in November, 1830, by Cuvier, Dumerit, and Latreille, Baron Cuvier being the writer of the report. In this memoir, for the first time so far as we know, the idea of zones of marine life is promulgated; these were four in number. A considerable portion of the memoir is devoted to the subject of the bristles in Annelids and to a description and classification of the Annelids of the coast of France. The reporters did not hesitate to express their satisfaction with the work the two friends had done, calling the special attention of the Academy to the "efforts heureux par lesquels ces deux habiles naturalistes sont parvenus à enrichir la Faune française d'espèces si nouvelles et si curieuses, et la zoologie en général d'observations si intéressantes." These happy efforts were but the forerunners of others carried on, in the case of Milne-Edwards, throughout a lengthened life.

In 1841 Milne-Edwards was appointed to the Professorship of Natural History in the Collége Royal de Henri IV., and about the same time we find him holding the Chair of Zoology and Comparative Physiology at the Faculty of Sciences, of which Faculty he was afterwards the Dean. On his friend Audouin's death, he was made Professor of Entomology at the Museum, Jardin des Plantes.

A considerable number of original memoirs, the titles of which it is here unnecessary to detail, were published about this period by Milne-Edwards in the *Annales des Sciences Naturelles*. This famous periodical first appeared in 1824, under the editorship of Audouin, Brogniart and Dumas. In 1834 the second series, from which geology and mineralogy were excluded, commenced under the joint editorship, for the zoological portion, of Audouin and Milne-Edwards, so that for now fifty years the zoological department has been under his management.

While labours as important as they were numerous secured for H. Milne-Edwards a high position among men of science, his name was also universally well-known and made popular by his elementary works on zoology. His "Eléments de Zoologie" were published in 1834 and were reissued in 1851 as a "Cours élémentaire de Zoologie." This work had an enormous circulation in France, and has not only been translated into several other languages, but also, until almost the other day, it formed the stock-in-trade, either as to its text or its illustrations, of most of the many small elementary works on natural history published in Europe.

In 1838 Milne-Edwards was elected a member of the Academy of Sciences in the section of anatomy and zoology. He was made an officer of the Legion of Honour in 1847, and a commander of this Order in 1861. In 1862 he succeeded Isidore Geoffroy Saint-Hilaire as Professor of Zoology at the Jardin des Plantes, and in a year or two afterwards was made assistant director of the museum.

Of his more important works as distinct from his memoirs may be mentioned his "Histoire naturelle des Crustacés," 1834-40. In this he was assisted by his friend Audouin, and it long remained as a standard authority on this group.

The "Histoire naturelle des Coralliares," 1857-60, was commenced after Milne-Edwards's return, in 1834, from a collectingtour on the coast of Algeria; but in 1847, in order to satisfy the calls of his publishers, he associated Jules Haime, so well known for his memoirs on the Polyps in the Palæontographical Society of London and in the *Annales des Sciences Naturelles*, with him in this work; but the death of Haime in 1856 compelled Milne-Edwards to complete the work himself. It is in a few tender words dedicated to the memory of Jules Haime.

"Leçons sur la Physiologie et l'Anatomie comparée de l'Homme et des Animaux" were published between 1857 and 1881, in fourteen volumes. The series is dedicated to his friend, M. J. Dumas, to whom he had dedicated the first work of his early pen. These lectures will always possess an importance to the student, from the immense mass of details, accompanied with copious references to the labours of others, that are brought within a limited compass.

"Recherches anatomiques et zoologiques faites pendant un Voyage sur les Côtes de la Sicile, &c.," forms a splendid quarto volume of over 850 pages, which are illustrated with nearly 100 coloured plates. This work is, for the most part, a corrected report of a series of memoirs contributed to the *Annales des Sciences Naturelles* by Milne-Edwards, A. de Quatrefages, and Emile Blanchard.

There can be little question that the name of H. Milne-Edwards will always rank high among the naturalists of the first half of the nineteenth century, and for years he was incontestibly one of the leaders of zoology. He was among the first who, not content with the study of the dead forms of animal life, made prolonged visits to the sea-coasts to study the living forms and to investigate their habits. These were days before biological stations were thought of and when the details of geographical distribution were little known. That Milne-Edwards's study of the geographical distribution of the lower forms of Invertebrates led him to the theory of there being centres of creation was what, from a purely zoological point of view, might have been expected; and when larger and truer views burst upon the world through the genius of Darwin, Milne-Edwards's mind, already preoccupied, was never altogether able to take them in. By the student of biology Milne-Edwards will be remembered by his theory of the division of physiological labour, one which threw an interesting light on many an intricate problem.

H. Milne-Edwards was an excellent linguist. English he spoke like a native. In manner courteous, he was kindly and affable to all. His house at the Jardin des Plantes was for years the focus of attraction for all the men of science in or visiting Paris. He was the possessor of a splendid library, the treasures of which were most freely at the services of students. He was a member of most of the learned Academies of Europe and America, and the possessor of several orders of State. Full of years and service, he died in Paris on July 29 last. As Geoffroy Saint-Hilaire was on his death succeeded by his son Isidore, so, happily for zoology, Henry Milne-Edwards has, in his son Alphonse, handed down his name and place to one every way worthy of both.

RADIANT LIGHT AND HEAT

Preliminary Notions

IT has been known from time immemorial that a sufficiently hot body when left to itself gives out light and heat, and likewise grows cold. It has also been known that a body not sufficiently hot to give out light may yet be capable of giving out heat, cooling as it does so.

If the above facts be studied scientifically they at once give rise to a series of important issues, all of which we are now in a position to reply to. These may be put in the form of the following questions:

(1) Is radiant light a substance or, if not, what is it?
(2) With what velocity does it move through space?
(3) Is radiant heat physically similar to radiant light?
(4) What is meant by a hot body?
(5) In what manner is the issue of radiant light and heat related to the cooling of the body?

Of these five questions the second was the first to

receive a solution, and this through the aid of astronomical observations.

Römer, a Danish astronomer, determined in 1675 the velocity of light by means of the eclipses of Jupiter's satellites. It so happens that the planes in which the earth and Jupiter move around the sun, as well as the plane in which Jupiter's satellites move around that planet, coincide very nearly with each other. As a consequence the first or nearest of Jupiter's satellites passes within the shadow of the planet at intervals of 42hr. 28m. 36s., and thus becomes obscured.

Now, if light were to travel instantaneously from Jupiter to the earth we should always see this obscuration at the moment when it took place. But even if light required time to travel, yet if the earth were always at a constant distance from Jupiter we should see the obscuration at a constant interval of time after its occurrence. Now Römer found that when the earth was furthest away from Jupiter there was a retardation in the time of the occurrence equal to 16m. 36s., as compared with that when the earth and Jupiter were nearest together.

It will be seen from the diagram (Fig. 1) that the

Fig 1.

earth and Jupiter are nearest together when the earth is between Jupiter and the sun, and that the two are furthest apart when the sun is between the earth and Jupiter. Hence it follows that the difference in the distances from each other of the two planets in these two positions is equal to the diameter of the earth's orbit, or 183,000,000 of miles. If, therefore, light takes 996 seconds to cross this distance it ought to travel at the rate of 184,000 miles per second.

The velocity of light has likewise been determined by experiment. The arrangement for this purpose adopted by Fizeau is the one most easily understood. It consists of a toothed wheel, which may be made to revolve with great rapidity. Now a ray of light is made to pass through one of the intervals between the teeth, and to fall upon a reflecting mirror placed at a considerable distance off in such a manner that when the wheel is at rest the ray will be reflected back through the same interval. If, however, the wheel is in rapid motion it is possible that during the time which the ray takes to travel to the reflecting surface and back again the wheel may have moved so much that the ray is caught by the next tooth, and not allowed to pass through; while, if the motion be still more rapid, the ray may get through the next interval, and so on. Without entering more minutely into the conduct of the experiment, it will at once be seen that we have here the means of measuring the velocity of light.

By these and similar methods this velocity is now very accurately known, and is found to be about 187,000 miles, or 300,000 kilometres per second.

The evidence is very strong that all varieties of light, whether red, orange, yellow, green, blue, indigo, or violet move through vacant space with the same velocity.

Having thus briefly replied to the second of these questions, let me now return to the first, and inquire as to the nature of radiant light. We are able to conceive of two, and only two, varieties of progress in space. The one of these is the progress of actual matter, the other the progress of a form. An arrow discharged from a bow, or a bullet from a gun, represents the former of these, while the ever-widening circles which follow the plunge of a stone into a pool of water represent the latter. The progress which is visible when the wind blows along a field of corn or grass is another good illustration of a moving form. Here the corn or the grass is certainly not carried along, and if the wind is so carried, yet we cannot see the wind. What we see is an advancing form due to the oscillating motion of the various heads of corn or blades of grass. In like manner when a cannon or a gun is discharged at some distance from us the noise reaches our ear after a greater or less interval, depending upon the distance. Here it would be absurd to suppose that certain particles of air had been shot all the way from the cannon into our ear with the constant velocity of 1,100 feet per second—this velocity in the case of a gun or pistol being likewise the same as when the most powerful cannon is discharged. It is well known that in this instance a blow is given to the air, thus causing an arrangement of condensed and rarified particles which progresses with a certain definite velocity. The speed of progress of this form may either be determined by direct experiment, or by calculation founded on the well known properties of air—the two methods agreeing perfectly well together.

Now in many respects there is a strong analogy between sound and light, and these very questions which have been asked for sound are equally appropriate in the case of light. Can it be thought likely that hot bodies emit myriads of very small particles, which pass through space with the enormous velocity of 187,000 miles per second? or again, is it likely that this velocity should be precisely the same for all bodies and for all temperatures?

It is a singular circumstance that the illustrious Newton, to whom science owes so much, and one of whose achievements was a correct, or nearly correct, analysis of the conditions of undulatory motion in air, should nevertheless have become a powerful advocate of the corpuscular theory of light, thus lending his great authority to retard the progress of the rival theory, which represents light as an undulatory motion, similar in many respects to that which constitutes sound.

It is to Huyghens in the first place, and to Young and Fresnel in more recent times, that we owe the establishment of the undulatory theory of light upon so firm a basis that the older hypothesis is now entirely forgotten, or regarded only as a scientific curiosity.

There are two ways in which a theory may break down. Its various assumptions may display a great lack of living energy, or, in other words, may exhibit inability to expand themselves so as to incorporate a large volume of fact. Each new fact would thus imply the construction of a fresh assumption, so that there would be as many hypotheses as facts. A cumbrous structure of this kind, it is needless to say, would be utterly useless as a scientific instrument, and would finally fall to pieces from its own weight.

Another mode in which such a theory may break down is by the promulgation of some statement which is ultimately found to be contrary to fact. The corpuscular theory of light has broken down in both of these directions. For, in the first place, it had to be propped up by many fresh assumptions devised solely for the purpose of explaining fresh facts, and wholly useless in any other respect. In the next place one of its fundamental statements was ultimately contradicted by an appeal to experiment, carried out by M. Foucault, an eminent French observer. According to the corpuscular theory, or that of emission, the velocity of light ought to be greater in water than in air. On the other hand, according to the undulatory theory, the velocity in water is less than in air. If, therefore, it can be shown that light moves faster in air than in water then the undulatory theory is right; if the contrary, then the theory of emissions is right. Foucault succeeded in showing by an experimental method that light travels faster in air than in water, and this result has

ever since been considered as decisive in favour of the undulatory theory.

We come now to our third question: Is radiant heat physically similar to radiant light? Here the difficulty is an instrumental one; the difficulty, in fact, of inventing something which shall do for dark heat what the eye can do for light.

At a comparatively early period Sir John Leslie devised his *differential thermometer*, with which he was able to obtain valuable results, to be hereafter alluded to. In this instrument we have two bulbs, A and B, filled with air, and connected together by a bent tube (Fig. 2) the lower

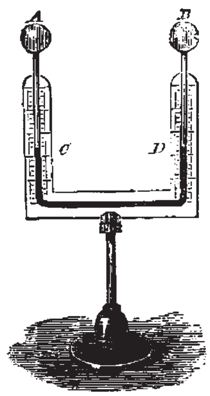

FIG. 2.

portion of which is filled with some coloured liquid, which ought not to be volatile. Let us begin by supposing that both bulbs are of the same temperature, and that under these circumstances the air is at the same pressure in both. The line between C and D, the surfaces of the liquid, in the two tubes will consequently be horizontal. Now suppose that the bulb A is heated, its air pressure is in consequence increased, and hence the liquid will be pushed down at C and up at D. In like manner if B is heated the liquid will be pushed down at D and up at C, and the change may be roughly taken as proportional to the difference in temperature between the two bulbs, this difference being supposed to be small. If, however, both bulbs are heated simultaneously, and to the same extent, there will be no motion in the liquid, inasmuch as there will be no difference in pressure of the air of the two bulbs.

In consequence of this mode of action the instrument has received the name of the differential thermometer;

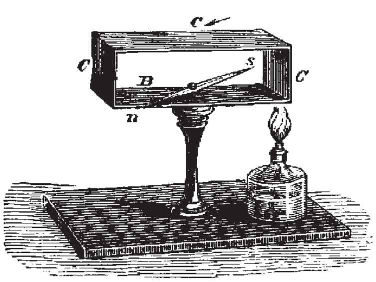

FIG. 3.

indeed, it is abundantly evident that what is measured is not the absolute temperature of A and B, but only the difference in temperature between the two.

Delicate as this instrument might at first sight appear to be, it forms but a poor substitute for the human eye, and had it not been for a new discovery, we should not have been able to make much progress in our knowledge of dark heat. The discovery alluded to is that of Seebeck, who found that in a circuit, composed of two metals soldered together, a current of electricity is produced when one of the junctions is heated, while the other is kept cool. If, however, both junctions be simultaneously heated to the same extent, no current is produced.

Here, then, we have an instrument similar in principle to that of Leslie, or, in other words, a new species of differential thermometer, and we shall now show that this arrangement is capable of being made extremely delicate as a measurer of small differences of temperature. The existence of a current of electricity is easily known by the motion of a magnetized needle, which tends to place itself at right angles to the direction of the current. Suppose now we have a circuit (Fig. 3), in which *C* denotes copper and *B* bismuth, and that we heat one of its junctions as in the Figure. We shall have, in consequence, a positive current following the direction of the arrow head, and the north pole of the needle will be pushed towards the observer as indicated in the Figure. When we make use of a magnet to measure a current we call our instrument a *galvanometer*. Our object, therefore, in this arrangement, is clearly to get as large a current as possible out of a small temperature difference, and then to measure this current by means of a galvanometer made as delicate as possible.

In order to obtain as strong a current as possible we must make use of a considerable number of junctions, as in Fig. 4, only in practice these junctions are very close

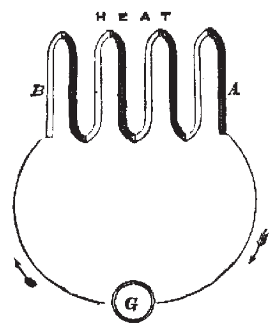

FIG. 4.

together. Here the heating influence is applied to the upper junctions, while the lower ones are kept cool. Another point is to select two suitable metals for our junctions—that is to say, metals the heating of which shall produce a powerful current. This is done by consulting a thermo-electric list of metals; in other words, a list such that the positive current shall go across the heated junction from the metal nearest the top to that nearest the bottom of the list.

The following is a series of this nature:

Bismuth.	
Nickel.	Silver.
Lead.	Zinc.
Tin.	Iron.
Copper.	Antimony.
Platinum.	Tellurium.

Now there is an important law which holds with reference to this series. If, for instance, we have a compound circuit, such as that in Fig. 5, connected with a galvanometer, we shall get the same current *in one direction* by heating through 1° C. the copper and tin junction, and also the tin and antimony junction, as we shall *in the opposite direction* by heating the antimony and copper junction. In other words, the various metals in the above list are to be regarded as being at so many different levels, and the strength of the current depends upon this difference of level, and not at all upon the exact number of halting places we make use of in

going from the one level to the other. It thus appears that we shall get the greatest effect by selecting two metals near the opposite extremities of the list. Bismuth and antimony are generallly the metals chosen, and 36 or 49 junctions of these are frequently used, the metals being packed close together, but insulated from each other, and thus forming a sort of cube, each end of which contains, say, 36 junctions. These junctions are generally covered with lamp-black. If the one end of this be heated we shall have a current in the one direction; if the other end, we shall have one in the other direction; while, if both ends be heated simultaneously and to the same extent,

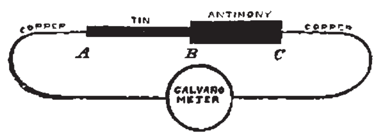

FIG. 5.

we shall have no current whatever. This arrangement forms what is termed a *thermopile*, and the cube of elements is generally encased in a brass covering presenting two terminals, in which the wires of the galvanometer are to be inserted and screwed tight. Inasmuch as this arrangement is generally used for viewing and measuring heat rays, a brass cone polished in the inside is often attached to the thermopile (Fig. 8) with the view of catching a large area of heat rays and reflecting them into the pile.

The galvanometer consists essentially of a magnet, which is delicately suspended by a very fine thread. Around it we have numerous coils of wire (but not in this case *very* numerous coils of *very* fine wire), which convey the current, each single coil counting separately in its action upon the magnet.

The various coils must, of course, be insulated from each other. A comparatively weak current will thus produce a visible effect if there be only a sufficient number of coils.

But yet the result so obtained is not the best, because we are having, after all, a strife between the influence of the current and that of the earth upon the small magnet. Assuming that the galvanometer was so placed to begin with that the magnet was in the magnetic meridian, then the current will tend to move the magnet to a position at right angles to this plane, while the earth's magnetic force will tend to keep it where it is. There is thus a strife between the two, and this will greatly interfere with the delicacy of the instrument. What we have

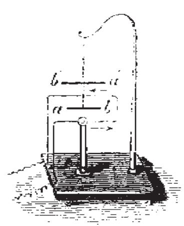

FIG. 6.

to do is so to counteract the earth's directive force that the little magnet may behave as if it was not under any external magnetic influence whatever.

A needle for which the directive effect of the earth's magnetic force is thus neutralised is said to be rendered *astatic*.

There are two ways in which this may be accomplished. We may use two needles of as nearly as possible the same strength, joined rigidly together with their poles in opposite directions, as in Fig. 6. Numerous coils of wire are wound around the lower needle, one of which we have exhibited. Here the upper current will tend to twist *b′* above the plane of the paper, while the lower current will act on *b′* in an opposite direction, this lower current, however, being further removed from the upper needle than the upper current, the latter will predominate, and the needle will, on the whole, be twisted round so as to place *b′* above the plane of the paper. Furthermore, the lower needle will be twisted round by both the upper and the under currents so as to place *a* above the plane of the paper, and hence the two needles will be twisted by the current in the same way, whilst the directive force of the earth's magnetism which opposes any motion of the needle will, by the arrangement above alluded to, be either altogether cancelled or rendered very small.

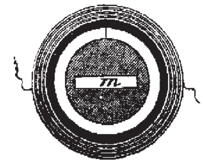

FIG. 7.

A galvanometer of this kind was employed by Melloni along with a thermopile as already described, and it was with these that he obtained the valuable results which we shall presently mention. But before dismissing this subject let us allude to some still further refinements made since the time of Melloni, which have contributed very greatly to increase the delicacy of this combination.

We have spoken about one way in which the effect of the earth's force may be neutralised, but we may likewise adopt the method of Sir W. Thomson, indicated in Fig. 8, where an external magnet, M, is so placed as to cancel the earth's action on the suspended galvanometer magnet which is supposed to be placed in the centre of G.

A still greater refinement consists in the joint use of both the methods now described. A system of two magnets

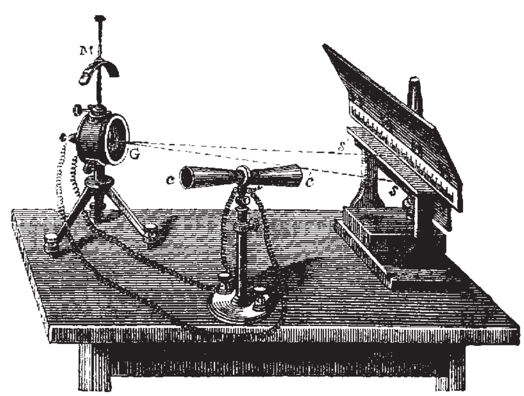

FIG. 8.

placed oppositely and united rigidly together is employed, a separate coil being made to surround each magnet. An external magnet is then so placed as to neutralize any directive force that may yet linger in the system. By this means very great delicacy almost amounting to instability may be obtained.

We shall conclude by mentioning an optical arrangement introduced by Sir W. Thomson, which greatly adds to the delicacy of the galvanometer. In this arrangement (Fig. 7) a small galvanometer magnet is attached to the back of a mirror, which mirror is suspended by a very fine thread.

Again (Fig. 8) there is a lamp behind the scale S S′, and a slit, or, better still, a round aperture below the scale, with a wire in its middle, is lighted up by the lamp, and a

reflected image of this lighted aperture thrown by means of the magnet-mirror, already described, upon the scale. This image may be made to move over a large space of the scale for a comparatively small motion of the mirror. If the image be that of a round circle of light, with a wire in the centre, we shall be easily able to read the position on the scale of the image of the wire, and by this means measure the motions of the mirror with very great accuracy and delicacy.

Having thus described in detail the various arrangements tending to make the thermopile and galvanometer a very delicate instrument for measuring radiant heat, let us proceed to discuss the reply which this combination gives to the question raised.

Melloni, who it must be remembered did not work with the instrument in its most perfect form, soon began to find that very many of those substances which were transparent for light, were, on the contrary, nearly opaque for dark heat. As he continued his labours he had, however, the satisfaction of finding a substance that was as nearly as possible equally transparent for both—this substance being crystallized rock salt.

He next found that just as by placing together two screens of coloured glass, one of which absorbs the redder portion of white light, while the other absorbs all but the redder portion, we may virtually stop all the radiation, so by certain combinations of screens it was equally possible to stop all the radiation from a source of low temperature heat. In the one case the result was perceived by the eye, and in the other by the thermopile. By this means he found that green glass and alum formed a peculiarly opaque combination. He next tried the same combination for the solar rays, and found that when they were first intercepted by a screen of green glass, they had a very feeble power of passing through a second screen of alum. The similarity in the behaviour of the rays from these two sources led him to imagine that heat accompanied with light and low temperature heat, are not physically dissimilar.

Again, the discovery by Melloni of the *diathermancy* or transparency for heat of rock-salt, led him to construct prisms and lenses of this material. By these means he proved that dark heat is capable of refraction, thereby exhibiting another bond of similarity between it and light. The subject was afterwards taken up by Forbes, who showed that the refrangibility of dark heat is inferior to that of the luminous rays. Forbes likewise showed that dark heat is capable of polarization and depolarization, and more recently other observers have shown that all the various properties of light may be exhibited at will in similar experiments with dark heat.

We have thus strong evidence for believing that dark heat is similar to light, the difference between them being physiological rather than physical, or, to speak more exactly, rays of dark heat may be presumed to differ from one another and from rays of light in no other respect than that in which the various rays of light differ from each other. In fine, the only difference is one of wave length or refrangibility, this being of such a nature that dark heat is less refrangible and has greater wave-length than light.

It is desirable at this stage to say a few words about the spectrum which is obtained from a luminous source by means of a prism.

Let us suppose, for the sake of simplicity, that the luminous source is a thread or slit of light, and that, by means of a lens, after the manner of a photographer, we wish to obtain an image of this slit of light and throw it upon a white screen. This image will appear as a white luminous slit of light. If, however, we interpose a prism between the source of light and the screen we shall obtain a very different result. In the first place the rays will be much bent by the prism, so that the screen will have to be placed in a very different position in order to receive the image of the slit. In the next place all the rays which go to constitute the light will not be bent to the same extent, so that the image of the slit given by one constituent ray will be thrown upon a different portion of the screen from that given by another. Thus the red rays will be least bent, then the orange, the yellow, the green, the blue, the indigo, and the violet, these last forming the most refrangible of the rays that enter into the composition of white light. What we shall really have, therefore, will be a great number of images of the slit placed side by side without any interval between them, these images being red at the one extremity and violet at the other. We shall, in other words, be presented with a long parti-coloured ribbon instead of a single white slit. This ribbon forms what is known as the *spectrum* of white light, and if before it is thrown upon the screen it be reflected from a plane mirror we may easily show, by making the mirror oscillate rapidly backwards and forwards, that this ribbon when in motion reconstitutes itself into a colourless white

The spectrum has various properties. Part of it can affect the eye—we say part of it, for there are dark rays at either extremity which the eye cannot perceive.

Part of it can perform certain chemical changes. Here again we say part of it, because there are certain chemical changes which certain rays seem at first sight incapable of producing.

All of it is, however, capable of heating a substance upon which it falls and by which it can be absorbed. We have thus three effects—the luminous, the actinic, and the heating effects; and certain portions of the spectrum are capable of exhibiting all the three.

If we take the action of the rays in blackening chloride of silver as a type of actinic influence we shall find that the maximum of the action is near, if not beyond, the most refrangible extremity of the visible spectrum.

If we take the effect upon the eye as our measure of light we shall find that the maximum is at the yellow, whilst if we take the heating effect of the spectrum under its usual circumstances of production we shall find that this has a maximum near the least refrangible extremity.

Now these considerations give rise to the following question: Is there only one thing present at one part of the spectrum, or are there three things?

At first it was imagined by some of the physicists of a past generation that there was in reality more than one thing and that the light and heating effects were produced by different agents. It was, however, afterwards found that if you operate on any portion of the spectrum by reflexion, absorption, polarisation, or in any other way, all the various qualities of that region are affected in the same proportion, so that if the light effect is reduced by one-half the actinic and heating effects are reduced by one-half likewise.

This decides the question, for we cannot imagine two or three separate agents existing at the same place and each possessing exactly the same physical qualities as the other; in other words, things which are not physically different from each other must be the same.

Thus we have now come to the conclusion that there is only one physical entity at any one part of the spectrum, and we have likewise been driven to see that in order to compare one part of the spectrum with another we must not use the eye, which has its own peculiarity, or some particular chemical substance which has likewise a partiality for certain rays.

What we have to do is to measure the amount of heat-energy possessed by the various parts of the spectrum, and this is done by allowing the rays in question to fall upon a suitable thermo-pile covered with lamp-black and then measuring the amount of heat to which they give rise by means of the indication of the galvanometer attached to the pile. A coating of lamp-black absorbs most of the rays, and if it is not absolutely

perfect in this respect it is at any rate more perfect than any other substance.

We can have now a very clear conception of what takes place when we heat a body such as coal. At first it gives out a spectrum consisting of rays, all of which are less refrangible than those of the visible spectrum. Soon, however, as the coal continues to rise in temperature, it not only increases the number of such rays but takes on others of a more refrangible nature, entering into the visible spectrum when it begins to be red-hot.

Thereafter it pushes its way further and further into this spectrum, taking on successively yellow and green rays, blue, violet, and actinic rays as the temperature still rises, until at length it shines forth with the lustre of the electric light or of the sun.

Let us now proceed to reply to the fourth question, What is meant by a hot body? At first it was supposed that heat was a substance possessing mass but not weight, an imponderable, as it was termed, which insinuated itself between the particles of bodies, thus causing them to expand. This substance was further supposed to be rubbed out by friction and beaten out by percussion. It will be perceived that we have here a corpuscular theory of heat very similar to that of light, the one forming indeed the natural sequel to the other. The experiments of Davy, in which two pieces of ice both below 0° were made to melt one another by their mutual friction, and those of Rumford, made in boring cannon, sufficed, in the course of time, to convince physicists that heat cannot be a substance, inasmuch as the melting of the ice in Davy's experiments, and the heat produced in those of Rumford, would equally imply the creation in large amount of the matter of heat. It was therefore concluded by both these experimentalists that heat is not a substance but rather a species of energy. That is to say the only difference between a hot body and the same body when cold is that, in the former state the molecules of the body are in violent motion backwards and forwards, while in the last state this kind of motion is much less. This is the dynamical theory of heat at present universally held. In it heat is regarded as a kind of energy, so that when heat is produced by friction or percussion, a certain quantity of visible energy disappears from the universe, while at the same instant an equivalent quantity of heat-energy appears, or is created.

A little reflection will, however, show us that there is not here any *real* creation or annihilation, but merely the simultaneous disappearance of one kind of energy and the appearance of another; in fact, nothing more than a transmutation of energy. Joule was the first to prove the definite mechanical relation that exists between the visible energy which disappears and the heat which is generated, and according to his experiments, if a pound of water were to fall from a height of 772 feet under gravity, and if all its visible energy on reaching the earth could at once be converted into heat, the water would be found to have risen 1° Fahr. in temperature. It will at once be recognised that just as the material or corpuscular theory of heat fits into the corpuscular theory of radiant light, so does the dynamical, or energetic theory of heat fit into the undulatory or wave hypothesis. We may, in fact, imagine the little particles or molecules of heated bodies to be in a state of continual vibration resembling in this respect a bell, or the string of a musical instrument, except that their vibrations are much more rapid than those which constitute sound.

And just as the vibrations of a bell are carried off by the gaseous medium, *i.e.* the air which surrounds the bell, and ultimately affect our ear, producing the sensation of sound, so are the vibrations of molecules carried off by a medium (the ether) which surrounds them and ultimately affect our eye, producing the sensation of light. This train of thought enables us at once to reply to our fifth question, and to assert that there is a definite mechanical relation between the amount of heat which leaves a hot body as it cools, and the radiant energy which accompanies the act of cooling. And this definite mechanical relation may be stated in very simple language. If, for instance, a pound of water cools through 10° Fahr. then the radiant energy which it gives out in the process of cooling, if this should be made to impinge upon another pound of water, and be entirely absorbed by it, would heat it through 10°, so that while the one pound of water has become 10° cooler the other has been raised an equal amount in temperature.

We are now in a position to reply as follows to the questions proposed:

(1) Radiant light consists of an undulatory motion in a medium called ether.

(2) It moves with the velocity of 187,000 miles per second.

(3) Radiant heat is physically similar to radiant light, the only difference being that its wave length is greater, and its refrangibility less than those of light.

(4) A hot body is one whose molecules are in rapid motion.

(5) There is an equivalence in energy between the amount of radiant light and heat emitted by a hot body and the sensible heat which the body loses. Radiant light and heat may be termed *radiant energy*.

Without pretending to enter here into a philosophical discussion it is instructive to notice that all of these questions which were capable of being answered in two ways were answered wrongly at first.

Although this procedure of the human mind has delayed the correct solution of a very important series of questions, yet we in the present age cannot reasonably complain of what has taken place. It has given us a confidence in our present views that we could hardly have had if the question between two alternative views had not been threshed out in the past.

We can thus look to the future without dismay, and need not fear the gradual rising into strength of a school which shall call in question any of the very important conclusions at which we have now arrived.

Surely there is an advantage in being wrong first and right afterwards, especially when it was a past generation who went wrong and we ourselves who are right!

BALFOUR STEWART

(*To be continued.*)

NOTES

WE understand that Prof. Huxley, P.R.S., has agreed, at the request of the Lords of the Committee of Council on Education, to continue to act as Dean of the Normal School of Science and Royal School of Mines at South Kensington, and also to be responsible for the general direction of the biological instruction therein.

THE Senatus of the University of Edinburgh resolved at its last meeting that a lectureship of comparative embryology be instituted, and appointed Mr. George Brook, F.L.S., as lecturer, subject to the approval of the University Court. Mr. Brook has for some time been engaged in making investigations for the Fishery Board for Scotland.

THE Indian *Civil and Military Gazette* writing of the ornithological collection presented by Mr. Allan Hume of the Civil Service of India to the British Museum, says that its value and extent are only now beginning to be realised. It amounts to 62,000 skins of all kinds, and it has cost Mr. Bowdler Sharpe, of the Natural History Department of the British Museum, more than three weeks of uninterrupted labour to pack and send it away. Even now the work is not at an end, for the collection of eggs, which is no insignificant one, remains to be despatched. The gift, which represents the labour and learning of a lifetime